Description of a Local Climatological Model for Improvement of Winter Road Surveys

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The local climatological model developed at the University of Gothenburg is described. The control measurements are mainly focused on two parts of the model: variation in road surface temperature under different synoptic conditions, and control functions in the model. The temperatures calculated by the model have been evaluated by use of temperature recordings along road stretches during different weather conditions. Both the actual road surface temperatures and the geographical extension have been analyzed, and the results show an overall good agreement between calculated and measured temperatures. Tests of the model were also carried out by use of temperature recordings from stations in the road weather information system. Analyses of temperature recordings from the field stations showed that the control functions included in the model are sufficient to separate the main types of weather conditions. However, it is necessary to develop the functions to take all possible temperature patterns into account. A possible way of developing the control criteria would be to include a comparison with historical temperature distributions before the data are extrapolated to be valid for road stretches.

Since the mid-1970s, research and development with emphasis on road climatology has been carried out at the Department of Physical Geography, University of Gothenburg. In 1985 a project started with the chief aim to develop a local climatological model to help in determining temperature variations along road stretches. The results from this project are reported elsewhere (*1–3*).

The system used today for surveying road slipperiness, the road weather information system (RWIS), consists of field stations at sites that are frequently exposed to slipperiness. The stations are connected to a central computer that enables surveillance of the road net. Lindqvist and Mattsson present the development of this system and a climatological background (*4*).

The idea behind the RWIS is that field stations are located at such sites that an indication of risk of slipperiness is received as early as possible. Since different weather situations give rise to different types of slipperiness, the stations are also located at different topographical sites: in shady areas, in valleys, or on bridges.

A disadvantage of today's RWIS is that only very localized information is received about temperature and risk of slipperiness, that is, long stretches of the road net lack sufficient surveillance. An extrapolation of data from the stations that is valid for road stretches is not possible without some kind of conversion in relation to the local topography. A method of accomplishing such a conversion would be to use a local climatological model of the type developed at the Department of Physical Geography. The model is developed by analysis of recordings from RWIS stations and from thermal mappings along road stretches. The result of this analysis is a number of empirical formulas with whose aid the relationship between local climate, topography, and weather is determined. The model is founded on the basic principle that a certain temperature pattern is repeated under similar weather conditions. Furthermore, the model uses the thermal mappings carried out along the road section in question and data from RWIS stations in the surroundings to determine the temperature variations along a road stretch.

This paper deals with tests of the local climatological model that have been performed within the frame of the project ARENA—TEST SITE WEST SWEDEN. The county of Halland in southwest Sweden was chosen as a test area, since an adaptation and application to this district were carried out during the development of the model (Figure 1). This paper focuses on

1. Control of the model's accuracy in relation to temperature measurements by a thermal mapping vehicle, and
2. Control of the model's function in relation to historical RWIS recordings and weather observations from synoptic weather stations in the area.

The methods used for control of the accuracy and function of the model are based on an analysis of thermal mappings and direct measurement results from the RWIS stations during different weather situations. Data from the two synoptic weather stations at Glommen and Torup were used for determining the amount of clouds and the regional wind velocity, which makes it possible to control the function of the model.

LOCAL CLIMATOLOGICAL MODEL

The use of topoclimatological parameters offers a possibility to establish the temperature variations along a road stretch under different weather conditions. The fundamental topographical parameters used as input for the calculations of these

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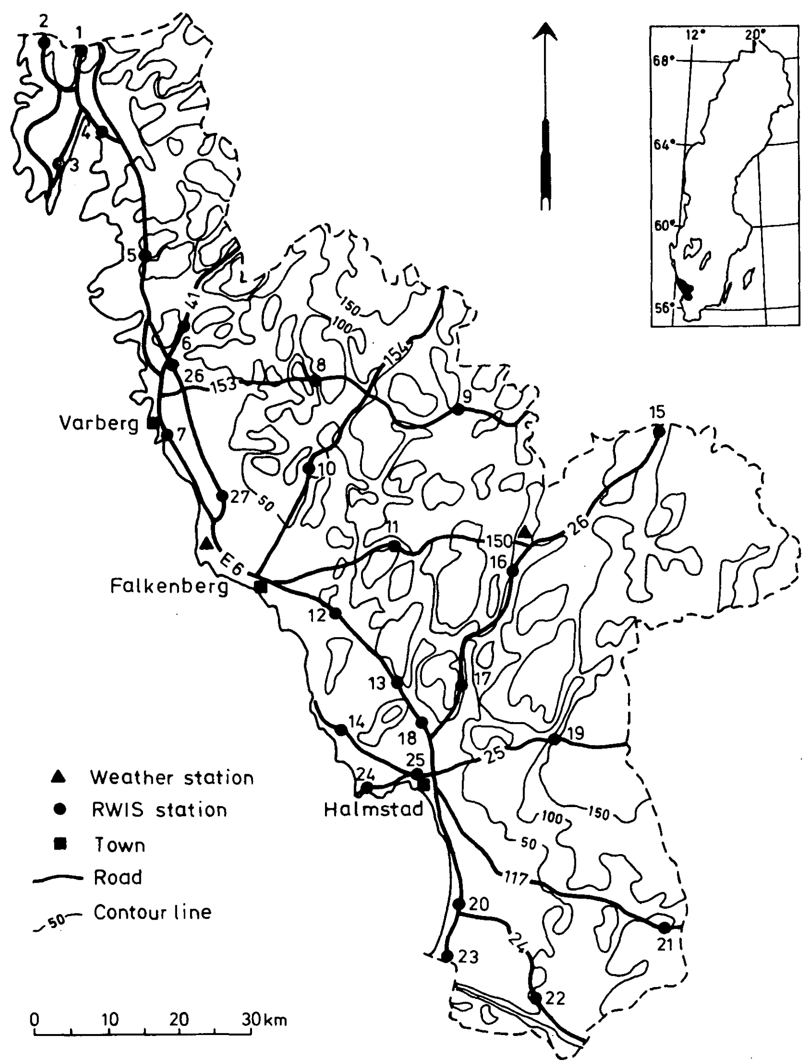

FIGURE 1 Map showing county of Halland with RWIS stations.

variations are

- Valleys: size (width and depth) determine the gathering and pooling of cold air. Exposure to wind is also an important factor for the formation of pooling and stagnation.
- Shaded areas: objects causing shadow can be described by form and size parameters in combination with orientation and distance from the road.
- Altitude: variations in altitude along the road are determined at 50-m intervals.
- Bridges: construction material, length and volume, and type are factors affecting the temperature pattern.

Other factors that must be included when discussing a specific area are proximity to water (large lakes or the sea) and the regional climate of the area.

When applying the model to a specific area, thermal mapping by car for the road sections in question as well as access to historical RWIS data are required. The data obtained from thermal mapping by car, along with analysis of topographical maps, give information of areas exposed to temperature fluctuations. The magnitude of the fluctuations under different weather conditions and between different areas is revealed from this type of data. The measuring trips by car also serve as a basis for division into topoclimatological segments along road stretches. Historical data from RWISs in the area are used to confirm the temperature fluctuations determined from the thermal mappings. These data also form the basis for establishing the temperature variations that can occur within the given area and for separating different types of temperature variations conditioned by the weather.

The different road stretches are classified with the aid of topographical maps but also by field measurements and field controls. The latter are especially important when it comes to establishing the exact orientation of road stretches and the type of objects causing shadow, which, in turn, is entirely decisive for the determination of shadow effects.

The relative extension and location of every type of segment included in the model are determined by integrating the information derived from the analysis of temperature data and information from maps and field controls. From the analysis of thermal mappings and RWISs, the basis is given for the formulas showing the relative temperature difference.

TEST OF LOCAL CLIMATOLOGICAL MODEL

For each section of the road stretches, a separate estimate is made for the prevailing temperature situation. The different temperature situations in question are the temperature patterns for (a) day/clear, (b) night/clear, (c) temperature reduction by altitude, and (d) regional pattern.

Day/Clear

Situations with the temperature pattern day/clear are characterized by large temperature variations occurring within a short stretch. The low temperatures are connected to road rock cuts, dense vegetation, or other objects shedding a dense shadow over the road. The difference in temperature arising on clear days between a screened and a sun-exposed area is determined, except for the shading object's properties, by the position of the sun.

Owing to the seasonal variation of the sun's course, the maximum possible temperature difference between sun-exposed and screened areas varies during winter from about 2°C in early January to as much as 15°C in the end of March. This relation between solar elevation and potential temperature difference is used for the calculation of screening effects during day/clear conditions. By knowing the day of the year the solar elevation is calculated, it is possible through the model to determine the relative temperature pattern formed by the alternating sun-exposed and screened parts along the road stretches. The relation between daily maximum solar elevation and the magnitude of road-surface temperature differences during day/clear conditions is illustrated in Figure 2.

When a road stretch is considered for the clear days, a division into five units is used, S0 through S5, where the index refers to the time of the day at which the road is screened:

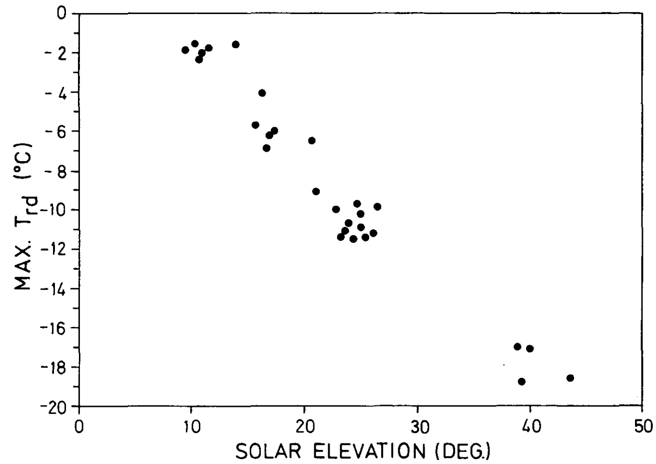

FIGURE 2 Plot of solar elevation versus maximum road-surface temperature difference (MAX.Trd) between sun-exposed and screened areas.

- S0 = exposed to sun,
- S1 = screened in the morning,
- S2 = screened during noon,
- S3 = screened in the afternoon,
- S4 = S1 and S2 in combination, and
- S5 = S2 and S3 in combination.

A thermal measurement by car was carried out along Road 153 during February 27, 1991, at noon. The weather was characterized by a clear sky and a light wind. For this situation the road surface temperature is calculated by the model to −1.6°C for the S2 and S4 segments, whereas the S0 segments are calculated to 5.8°C, giving a difference of 7.4°C between screened and sun-exposed segments.

A comparison between calculated and measured values (Table 1) shows that the regions segmented as screened sites have the lowest temperatures. The difference in absolute temperature between calculated and measured values is tolerably small. The largest differences appear at sun-exposed S0 seg-

TABLE 1 Control Measurements Along Road 153 on February 27, 1991, at 12:00 p.m.

Distance (km)	Type of segment	Calculated temp. (°C)	Measured temp. (°C)	Difference
0-11.5	S0	5.8	6.4	0.6
11.5-12.5	S2	-1.6	-2.0	0.4
12.5-15.2	S0	5.8	7.7	1.9
15.2-16.5	S4	-1.6	-2.1	0.5
16.5-17.8	S0	5.8	4.1	1.7
17.8-19.3	S4	-1.6	-1.6	0
19.3-22	S0	5.8	6.0	0.2
22-23.5	S4	-1.6	-1.8	0.2
23.5-25	S0	5.8	5.4	0.4

ments, 1.9 and 1.7°C, respectively. This can be explained by the inclination of the road. Most important is that the calculated values for the screened segments differ marginally from the measured ones and also that the error is negative, that is, the calculated value indicates a somewhat lower temperature than the measured value. The error is throughout less than 0.5°C for seven of nine segments, which must be regarded as a good agreement between calculated and measured temperature values.

Night/Clear

The differences in temperature during clear nights are mainly determined by two factors: the possibility of cold air pooling and the exposure of a certain area to wind. Cold air pooling occurs in low-lying parts, such as valleys and small hollows, provided that there are open surfaces that can drain the cold air to the bottom. There is an obvious connection between the depth and width of a valley and the temperature difference arising between the bottom and the top of the valley (*5*). This geometrical dependence makes it possible to calculate the temperature variation caused by different types of valleys.

The presence of valleys and small-sized hollows is generally entirely decisive for the variation in air and surface temperature during clear nights with light winds. As far as the county of Halland is concerned, however, the exposure to wind is the most important factor. This is due to the geographical position, that is, the proximity to the sea, as well as the variation of the forest cover within the county. The regions in which a large cold air pooling could occur are the open areas near the sea. The formation of strong cold air lakes is often prevented, however, since within this area the exposure to wind is so great that the air cannot be stabilized.

When examining historical data from the RWIS stations in the county of Halland and from the measuring trips by car that were carried out as a basis for situating the stations, it was ascertained that the regions with the lowest temperature values during clear nights are the forested areas in the eastern part of the county. However, also within this part variations occur governed by the local topography and the different degrees of forest density.

The fact that the lowest temperatures occur within the forested area complicates the calculation of the variation in surface temperatures considerably. The canyon created on both sides of the road that passes through a dense forest influences the air and the road surface in different ways. The forest canyon causes the wind exposure to be minor, and thereby a stabilization of the air can easily occur. It is comparatively common for the stations in the eastern part to have air temperatures that are 6 to 10°C lower than those of the western stations.

The road surface, however, is not affected in the same way as the air by the surrounding forest. The cooling of the road is reduced considerably because of the back radiation emanating from the nearest trees—that is, the surface radiation is prevented by trees, which causes the temperature drop to be less than would be the case if an equally large difference in air temperature affected the road within an open area.

The largest variation in temperature in the study area occurs between the coastal zone and the eastern forested area, as previously discussed. Because of this, the control measurements have been focused on the roads perpendicular to the coastline and which crosses the forested part of the county.

During the night of November 20–21, 1991, two measurements by car were carried out along Road 153, where Stations 8 and 9 are located. The first measurement trip started at 8:00 p.m. and the second at 5:00 a.m., both at the road crossing E6/153.

Both temperature recordings gave the same result: a general decrease of the air temperature by approximately 5 to 6°C from the coastline toward the county border. However, no such general trend can be found for the road-surface temperature. This can be explained by the matter previously discussed: namely, the reduced drop in surface temperature in the forested part of the count owing to the obstruction of the long-wave radiation caused by the trees close to the road.

The result from the control measurements and the calculated surface temperature values by use of the local climatological model are presented in Table 2. There is a general good agreement between the calculated and measured temperatures: 9 segments out of 11 agree within 1.0°C. However, further studies are planned to deal with the relationship between a specific sky view factor and the surface temperature development. Formulas based on this type of relationship will further increase the readability of the predictions produced by the model.

Temperature Reduction by Altitude

During situations when the sky is overcast and it is windy, the temperature variations caused by local topography are greatly reduced. When wind and clouds cause the air mass of the atmosphere to mix completely, the temperature pattern is determined by the altitude above sea level—that is, the temperature drops by increased altitude above sea level.

As for Halland, the altitude conditions vary from 0 and 200 m above sea level. This implies that temperature differences of 1.5 to 2°C can arise under overcast and windy conditions. Figure 3 exemplifies a situation in which temperature reduction by altitude is prevailing (December 8, 1991, 8:00 p.m.). The surface temperatures at the different RWIS stations in the county are plotted against the altitude. The sky was overcast with winds varying from 2 to 6 m/sec. The lowest air temperature, 2.1°C, was recorded at the highest-situated RWIS station, Station 19. A regression analysis shows a good correlation between altitude above sea level and surface temperature. The regression function

$$\text{RST} = 4.0 - 0.01H$$

where RST is the road-surface temperature and H the altitude above sea level indicates a decrease in temperature by the equivalent of 1°C/100 m. The correlation is .77, which means that the relationship can be considered ensured.

The model tests whether this temperature pattern (temperature reduction by altitude) will be valid with light or strong winds prevailing and whether the criterion day/clear has been eliminated during daytime. A validity test of the pattern implies that the temperature reduction calculated should

TABLE 2 Control Measurements Along Road 153 on February 20–21, 1991, at 8:00 p.m. and 5:00 a.m.

Segment	Calculated temp. (°C) 2000 h	Measured temp. (°C) 2000 h	Calculated temp. (°C) 0500 h	Measured temp. (°C) 0500 h
1	-4.5--5.5	-3.5--4.5	-7.0--8.0	-7.0--8.0
2	-4.5--5.5	-4.5--5.5	-6.0--7.0	-6.0--7.0
3	-3.5--4.5	-2.5--3.5	-5.0--6.0	-5.0--6.0
4	-4.5--5.5	-4.5--5.5	-6.0--7.0	-7.0--8.0
5	-3.5--4.5	-3.5--4.5	-5.0--6.0	-6.0--7.0
6	-4.5--5.5	-4.5--5.5	-8.0--9.0	-8.0--9.0
7	-3.5--4.5	-3.5--4.5	-7.0--8.0	-7.0--8.0
8	-4.5--5.5	-4.5--5.5	-8.0--9.0	-8.0--9.0
9	-3.5--4.5	-3.5--4.5	-7.0--8.0	-7.0--8.0
10	-4.5--5.5	-4.5--5.5	-8.0--9.0	-8.0--9.0
11	-3.5--4.5	-3.5--4.5	-7.0--8.0	-7.0--8.0

be less than 1.5°C/100 m and that the correlation should be high.

The temperature pattern in Figure 4 shows a calculated situation on January 16, 1991, at 11:00 a.m. for part of the northern region in Halland, which results in the temperature reduction by altitude. The thermal map shows the prevailing temperature pattern where the temperature difference is divided into four classes with a class width of 0.5°C (Figure 4). The lowest temperature in the high-lying parts is marked with a cross-ruled screen and is equal to −1.0 to −1.5°C. The highest temperature is marked in white, which is equal to 0.5 to 0°C, which means that the temperature span in this situation is a good degree between the coldest and the warmest parts. In this type of weather situation, the segmentation follows the absolute altitude above sea level along the road, and this temperature pattern is verified by the recorded temperatures at the RWIS stations in the actual area.

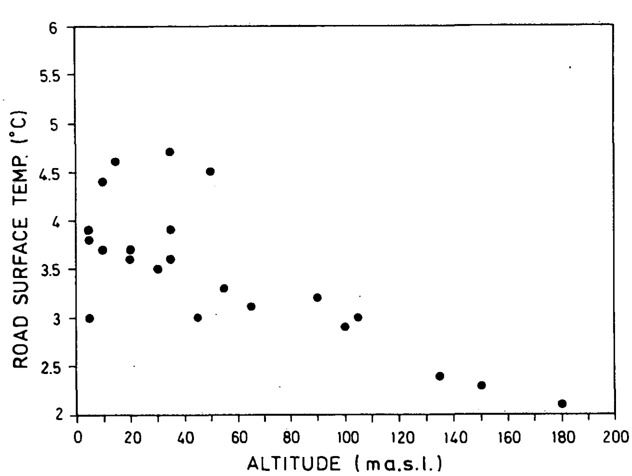

FIGURE 3 Plot of road-surface temperature versus altitude for RWIS stations in county of Halland during cloudy windy situation.

Regional Pattern

Regional pattern is the temperature criterion chosen by the model when day/clear, temperature reduction by altitude, and night/clear are eliminated from earlier calculations in the test algorithm.

The regional pattern is based on the segmentation being performed in such a way that an adaptation to existing RWIS stations can be done by a formula for each segment. An example of the segmentation used for regional pattern is shown in Figure 5. The situation is from January 16, 1991, at 2:00 p.m. The model tests whether there is a temperature reduction by altitude, but in this case the given condition is not fulfilled and the model chooses to work with regional pattern. The temperature distribution at the regional pattern is such that the variation cannot be systematically tied up to specific topographical parameters. In the case of temperature distribution regional pattern, the individual RWIS stations exert a direct importance for the different segments. The segments are placed in such a way that the geometrical distribution of the RWIS stations reflects the segments. The regional temperature distribution is therefore decisive for the determination of the formulas and for the segmentation in this type of situation.

DISCUSSION OF RESULTS

The advantage of using a local climatological model of the kind presented in this paper is not only that a complete temperature surveillance becomes possible but also that a considerably more differentiated picture can be received that can serve as an important aid when giving priority to combatting slipperiness in different areas or on road stretches within a working district. Moreover, the model offers great advantages when combining small surveillance areas into larger ones because, for an effective combatting of slipperiness, there is not the same need for local knowledge of areas exposed to slip-

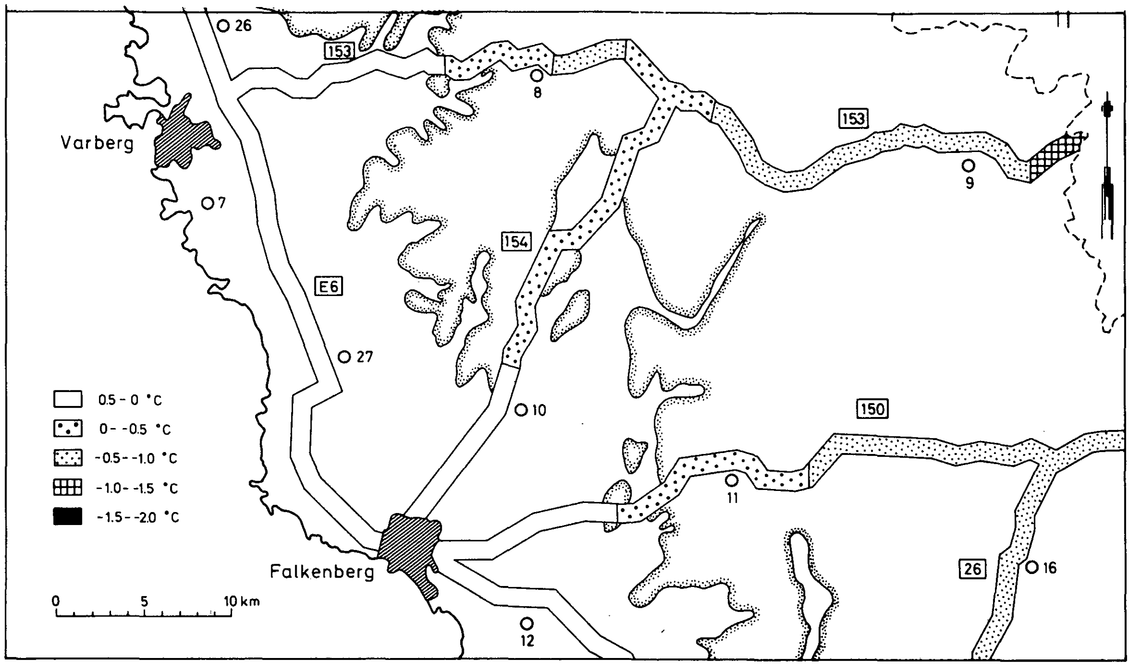

FIGURE 4 Calculated road-surface temperature for January 16 at 11:00 a.m.

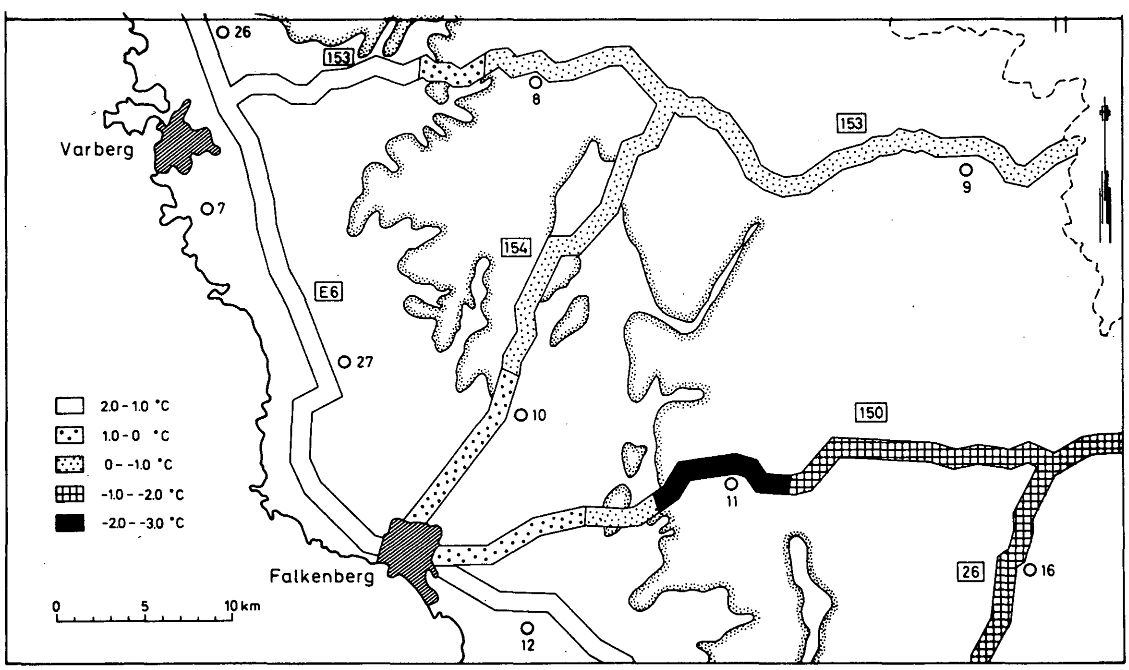

FIGURE 5 Calculated temperature distribution for episode categorized as regional pattern.

periness along certain road stretches. If the combatting of slipperiness can be made more effective, the number of accidents will decrease and the use of devices for eliminating slipperiness can be reduced.

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